Nuclear Smoke, Global Warming, and Ozone Depletion: Policy Responses to Anthropogenic Environmental Threats

Alan Robock[1], Owen B. Toon[2], Richard P. Turco[3],

Luke Oman[1,4], Georgiy L. Stenchikov[1], and Charles Bardeen[2]

[1]Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey

[2]Department of Atmospheric and Oceanic Sciences and Laboratory for Atmospheric and Space Physics
University of Colorado, Boulder

[3]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles

[4]Now at Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland

Submitted as a Forum article to *EOS*

March, 2007

Corresponding Author:
Alan Robock
Department of Environmental Sciences
Rutgers University
14 College Farm Road
New Brunswick, NJ 08901
Phone: 732-932-9478
Fax: 732-932-8644
E-mail: robock@envsci.rutgers.edu

Humans have come to the realization that pollution of the atmosphere with gases and particles in the past 50 years is the dominant cause of atmospheric change. While land-use change can produce large *regional* effects, global ozone depletion, global warming, and nuclear smoke are all actual or potential *global* adverse human impacts on our fragile environment, each with severe consequences for humanity. These effects were, or would be, inadvertent, unplanned consequences of normal daily activities, defense policies of many nations, and nuclear proliferation, and we seek ways of continuing our normal lives while protecting ourselves from environmental catastrophe.

Ozone depletion and global warming are already happening, while drastic cooling from smoke from nuclear-generate fires has so far been avoided. These three related human threats to the environment have been addressed with quite different policy responses, and with varying degrees of success so far.

The Montreal Protocol in 1987, the world's first global environmental treaty, was successful in pushing society to find replacements for ozone-depleting substances, chiefly chlorofluorocarbons, for refrigeration, air conditioning, foam blowing, aerosol propellants, and other applications. As a result, the concentration of these substances has started to decrease in both the troposphere and stratosphere. Ozone has begun a gradual recovery and may reach its pre-1980 levels by the middle of the current century [*Ajavon et al.*, 2007]. The treaty includes built-in, continuing meetings of the parties, which have produced amendments to take into account the latest observations and scientific understanding, produced for them in the regular World Meteorological Organization Ozone Assessments, and to adjust emission regulations to ensure ozone recovery as fast as possible. Mario Molina, Sherwood Rowland, and Paul Crutzen were awarded Nobel Prizes in Chemistry for developing the scientific basis for understanding this problem.

The United Nations Framework Convention on Climate Change in 1992 was signed by 194 countries, and has been ratified by 189 countries as of February, 2007. It was signed and ratified by the United States in 1992, came into force in 1994, and states, "The ultimate objective of this Convention ... is to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It, too, has a built-in mechanism for periodic "conferences of the parties" to develop mechanisms to meet its objective. The Kyoto Protocol, adopted at the third session of the Conference of the Parties in 1997 entered into force on February 16, 2005, after ratification by Russia. This protocol by itself will not meet the Convention objective, but it is a step forward, and there are signs that even in the United States, public opinion is reaching a tipping point toward serious policy responses to deal with the problem [*Gore*, 2006].

Although complicated by issues of national defense and prestige, nuclear proliferation has many aspects in common with global environmental issues, but they have not been considered in the same sort of policy framework. Casualties from the direct effects of blast, radioactivity, and fires resulting from the massive use of nuclear weapons by the superpowers would be so catastrophic that we avoided such a tragedy for the first six decades after the invention of nuclear weapons. The realization in the 1980s, based on research conducted jointly by Western and Soviet scientists [*Crutzen and Birks*, 1982; *Turco et al.*, 1983; *Aleksandrov and Stenchikov*, 1983; *Robock*, 1984, *Pittock et al.*, 1986; *Harwell and Hutchinson*, 1986], that the climatic consequences, and indirect effects of the collapse of society, would be so severe that the ensuing nuclear winter would produce famine for billions of people far from the target zones, may have been an important factor in the end of the arms race between the United States and the Soviet Union [*Robock*, 1989]. Arms reductions since the 1980s (Fig. 1) have cut the global nuclear arsenal to 1/3 of its prior size, and the United States and Russia have much improved relations, symbolized by joint operation of the International Space Station.

But now the world faces the prospect of other states developing small, but remarkably deadly, nuclear arsenals. *Toon et al.* [2007] address these policy issues in the context of nuclear arms control, but here we focus more specifically on policy implications related to environmental changes. Twenty years after the threat of nuclear winter was discovered, we now ask:

1. Although the Cold War and its associated nuclear arms race are over, could remaining nuclear arsenals still produce nuclear winter?
2. What would be the consequences of the use of a much smaller number of nuclear weapons in a regional nuclear conflict on the global environment?
3. Is it time for a global nuclear environmental treaty?

The onset of nuclear winter following a full scale conflict was widely debated during the 1980s. As with both global ozone loss and global warming, the scientific community found the scientific basis for nuclear winter to be sound (e.g., Pittock et al., 1986). However, as with both global ozone loss and global warming there was a vocal minority who sought to discredit the work, largely by obfuscation. The answer to question 1 was already clear in 1990 [*Turco et al.*, 1990; *Sagan and Turco*, 1990] and our understanding has not changed since then. The answer is yes; without further large cuts in the American and Russian nuclear arsenals, the use of current arsenals in a full-scale nuclear war would still produce nuclear winter, threatening the lives of billions of people [*Robock et al.*, 2007].

Our new work also answers question 2. *Toon et al.* [2006] recently showed that the direct effects of even a relatively small number of nuclear explosions would be a disaster for the region in which they would be used. A single low yield weapon used in a modern megacity can cause more than 1,000,000 casualties. *Toon et al.* [2006] found that a regional war between the smallest current nuclear states involving 100 15-kt explosions (a number of weapons likely to exist in the arsenals of new nuclear states – India and Pakistan are estimated to have 110-180 weapons between them) could produce direct fatalities comparable to all of those worldwide in World War II.

Fires inevitably ignited by nuclear bursts in cities, paralleling the firestorm in Hiroshima, would release copious amounts of light-absorbing smoke into the upper atmosphere. *Toon et al.* [2006] showed that 100 small nuclear weapons detonated within cities may be capable of generating one to five million tons (1-5 Tg) of carbonaceous smoke particles with the potential to create greater optical and radiative perturbations in Earth's atmosphere than major volcanic eruptions like those of Mt. Pinatubo in 1991 or Tambora in 1815. The latter event has been associated with the "Year Without a Summer" in 1816, but the nuclear smoke effects would last much longer [*Robock et al.*, 2006]. Smoke from urban firestorms in such a conflict would produce significant global temperature and precipitation changes, lasting a decade or more, shortening the growing season in the midlatitudes by a month in major agricultural areas, and thus impacting world food supplies [*Robock et al.*, 2006].

Simulations for this new work were carried out using the latest NASA Goddard Institute for Space Studies climate model, ModelE [*Schmidt et al.*, 2006], the result of decades of NASA investment, and the hard work and dedication of a large number of scientists supported by NASA. Because ModelE is able to simulate the entire troposphere, stratosphere, and mesosphere, from the Earth's surface up to 80 km, and interactively transports black carbon aerosols in response to solar heating and changing wind circulation, we were able to produce fundamentally new results, showing that the smoke would persist in the atmosphere far longer than previously assumed. *Robock et al.* [*2007*] also show that early results suggesting that nuclear fall instead of nuclear winter would follow a full-scale war were based upon climate models which were not adequate to fully address the problem because they did not have deep enough atmospheres, and could not be run long enough.

We propose that the answer to question 3 is "yes." Work on nuclear winter has already led to important policy decisions [*Robock*, 1989]. A nuclear war cannot be won. Even a "first strike" would be suicidal. Likewise, a "limited" nuclear war could cause severe effects, if targeted at cities and industrial areas, and it is doubtful that a nuclear war could ever be limited. "Star Wars" (Strategic Defense Initiative, now the Missile Defense Agency) is not the answer, since this system will always be "leaky." The indirect effects of nuclear winter could be even greater than the direct effects, leaving many innocent victims in non-combatant nations.

Future nuclear arms treaties need to address the environmental consequences of the total number of weapons they allow to remain in the arsenals. Arms reductions of the past 20 years were not enough to protect the planet from the possible consequences of nuclear smoke, and putting nuclear weapons into the hands of more and more countries only increases the potential dangers. Figure 1 shows that Russia and the U.S. have reduced their arsenals by 1/3 since their peak in the 1980s. By 2012, current agreements call for reductions in deployed weapons that will be about 1/20 of the levels in the mid-1980s. However, these deployed weapons will still be 10 times greater than those of China, France or the United Kingdom, and many more weapons may remain in storage. Hence much larger reductions are needed in Russian and U.S. weapons.

To make matters worse, there has been a steady increase in the number of nuclear weapons states (Fig. 2). Between 1970, when the nuclear proliferation treaty was signed, and 1980 only non-signatories to the treaty such as Israel and India created weapons. Now however, signatory countries such as North Korea, and Iran are violating the treaty. Unlike in prior periods, the world no longer seems united in the goal to prevent nuclear proliferation.

The problems of ozone depletion, global warming, and nuclear smoke are related and linked. In each case changes to the environment are substantial. Nuclear smoke can change the climate, and impact the ozone layer [*Mills and Toon*, 2006]. Moreover some solutions to global warming can contribute to nuclear instability. Nuclear power plants, because of their low greenhouse gas emissions, have been suggested as a way to mitigate global warming, but as part of their fuel cycle can be used as sources of highly-enriched uranium and plutonium, and therefore can be used for nuclear weapons production. Indeed countries such as North Korea and Iran have obtained help from the rest of the world to construct nuclear power plants ostensibly for power production, but with the ulterior motive of building weapons. We need holistic policies to solve these linked human threats to our environment, so that the solution to one does not compromise the solutions to the others.

References

Ajavon, A. N., D. L. Albritton, and R. T. Watson, Co-Chairs (2007), *Scientific Assessment of Ozone Depletion: 2006*, World Meteorological Organization Global Ozone Research and Monitoring Project—Report No. 50 (World Meteorological Organization, Geneva).

Aleksandrov, V. V., and G. L. Stenchikov, (1983), On the modeling of the climatic consequences of the nuclear war, *Proc. Applied Math, Computing Centre, USSR*, (Academy of Sciences, Moscow), 21 pp.

Crutzen, P. J., and J. W. Birks (1982), The atmosphere after a nuclear war: Twilight at noon, *Ambio*, *11*, 115-125.

Gore, A. (2006), *An Inconvenient Truth*, (Rodale Press), 325 pp.

Harwell, M. A. and T. C. Hutchinson, Eds. (1986), *Environmental Consequences of Nuclear War, SCOPE 28. Volume II, Ecological and Agricultural Effects*, (John Wiley & Sons, New York).

Mills, M., and O. B. Toon (2006), Blown away: The Impact of nuclear conflicts on the global stratospheric ozone layer, *Eos Trans. AGU*, *87(52)*, Fall Meet. Suppl., Abstract U14A-07.

Norris, R. S., and H. M. Kristensen (2006), *Bull. Atomic Scientists*, *62(4)*, 64.

Pittock, A. B., T. P. Ackerman, P. J. Crutzen, M. C. MacCracken, C. S. Shapiro, and R. P. Turco, Eds. (1986), *Environmental Consequences of Nuclear War, SCOPE 28. Volume I, Physical and Atmospheric Effects*, (John Wiley & Sons, New York).

Robock, A. (1984), Snow and ice feedbacks prolong effects of nuclear winter, *Nature*, *310*, 667-670.

Robock, A. (1989), Policy implications of nuclear winter and ideas for solutions, *Ambio*, *18*, 360-366.

Robock, A., L. Oman, G. L. Stenchikov, O. B. Toon, C. Bardeen, and R. P. Turco (2006), Climatic consequences of regional nuclear conflicts, *Atm. Chem. Phys. Disc.*, *6*, 11,817-11,843.

Robock, A., L. Oman, and G. L. Stenchikov (2007), Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences, Submitted to *J. Geophys. Res.*, doi:2006JD008235.

Sagan, C., and R. Turco (1990), *A Path Where No Man Thought - Nuclear Winter and the End of the Arms Race*, (Random House, New York).

Schmidt, G. A., et al. (2006), Present-day atmospheric simulations using GISS ModelE: Comparison to in situ, satellite, and reanalysis data, *J. Clim.*, *19*, 153-192.

Toon, O. B., R. P. Turco, A. Robock, C. Bardeen, L. Oman, and G. L. Stenchikov (2006), Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism, *Atm. Chem. Phys. Disc.*, *6*, 11,745-11,816.

Toon, O. B., A. Robock, R. P. Turco, C. Bardeen, L. Oman, and G. L. Stenchikov (2007), Consequences of regional-scale nuclear conflicts, *Science*, *315*, 1224-1225.

Turco, R. P., O. B. Toon, T. P. Ackerman, J. B. Pollack, and C. Sagan (1983), Nuclear winter: Global consequences of multiple nuclear explosions, *Science*, *222*, 1283-1292.

Turco, R. P., O. B. Toon, T. P. Ackerman, J. B. Pollack, and C. Sagan (1990), Climate and smoke: An appraisal of nuclear winter, *Science*, *247*, 166-176.

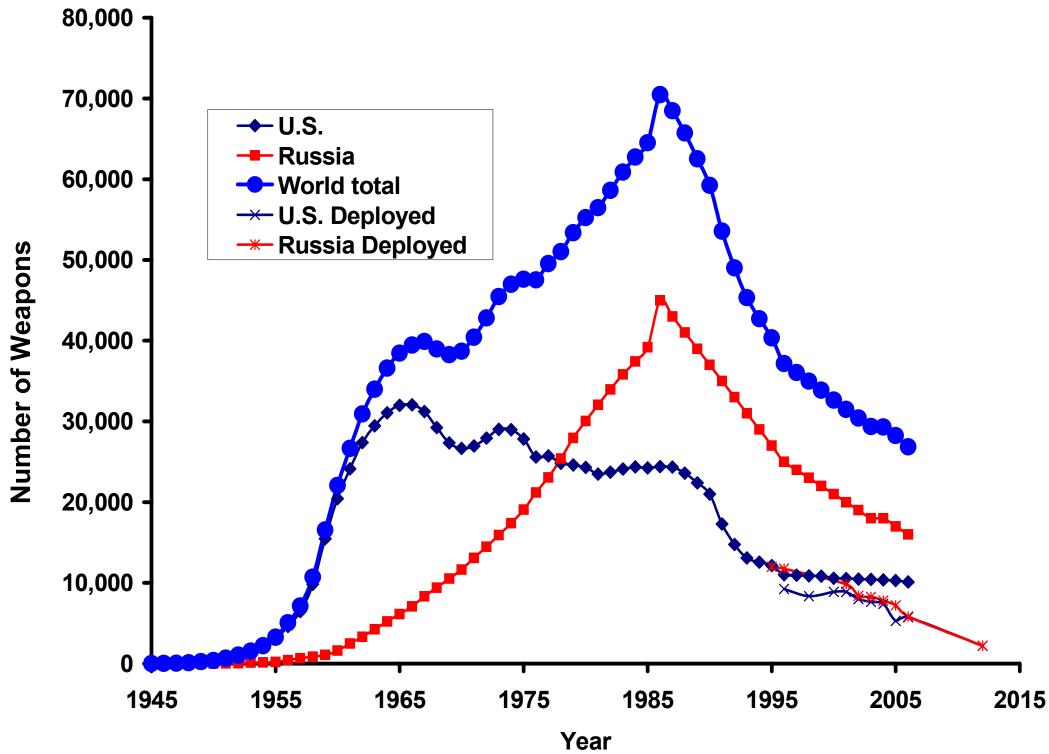

Figure 1. Number of nuclear warheads in Russia (USSR), the U.S. and the total for all the nuclear weapons states [*Norris and Kristensen*, 2006]. Russia and the U.S. have more than 95% of the warheads worldwide. The number of warheads began to fall after 1986 following the Intermediate-Range Nuclear Forces Treaty, and by 2005 was about one-third of its value at the peak in 1986. Current treaties do not require a future reduction in the numbers of warheads, only a reduction in the numbers of warheads that are on strategic delivery systems. Weapons on strategic delivery systems should decline to 1700-2200 for each country by 2012.

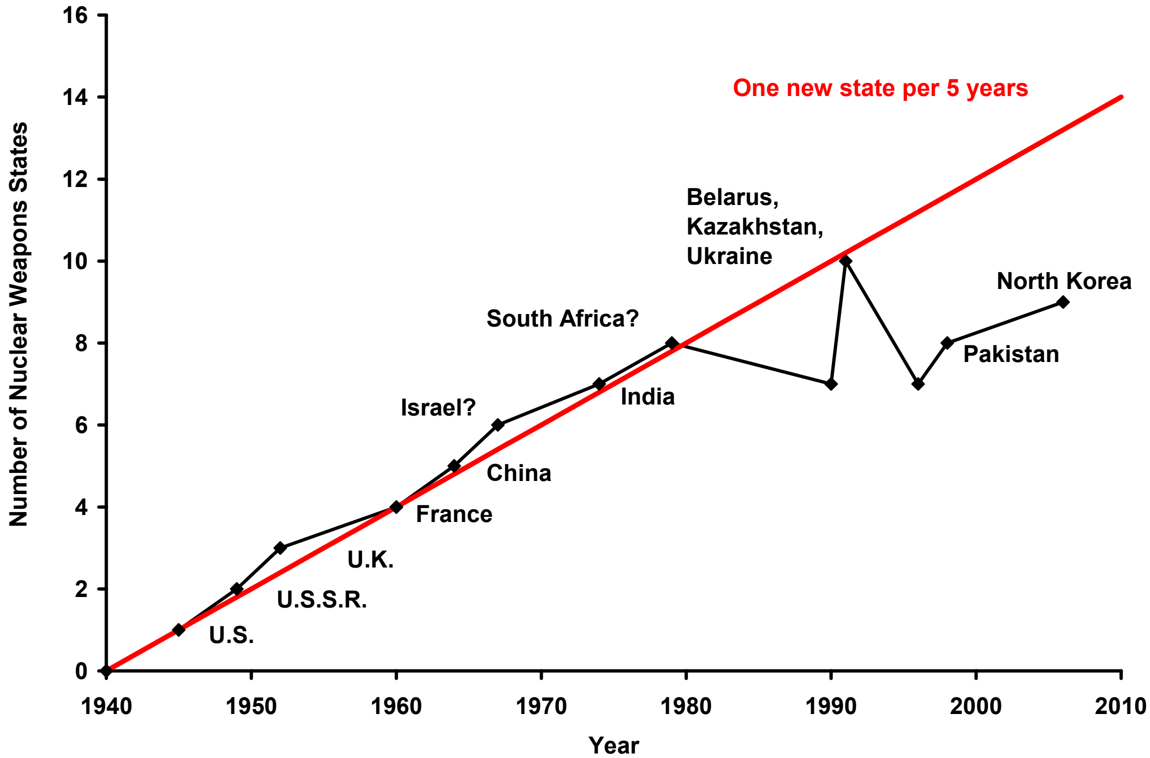

Figure 2. New nuclear states have steadily appeared since the invention of nuclear weapons. In this graph the date of the first test, or the date when weapons were obtained, is noted. Israel and South Africa did not test weapons so their dates to obtain weapons are uncertain. South Africa abandoned its arsenal in the 1990s. Ukraine, Belarus, and Kazakhstan also abandoned the weapons they inherited after they left the Soviet Union.